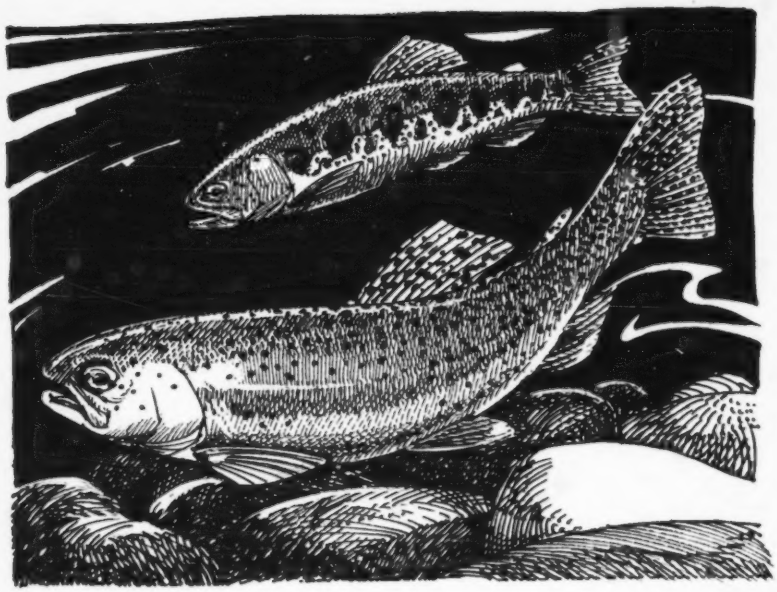
Fish & Wildlife Division

SPECIES AT RISK

Status of the Athabasca Rainbow Trout (*Oncorhynchus mykiss*) in Alberta



Alberta Wildlife Status Report No. 66

Alberta Conservation Association

Government of Alberta

Status of the Athabasca Rainbow Trout (*Oncorhynchus mykiss*) in Alberta

Prepared for:
Alberta Sustainable Resource Development (SRD)
Alberta Conservation Association (ACA)

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PREFACE

Every five years, the Fish and Wildlife Division of Alberta Sustainable Resource Development reviews the general status of wildlife species in Alberta. These overviews, which have been conducted in 1991 (*The Status of Alberta Wildlife*), 1996 (*The Status of Alberta Wildlife*), 2000 (*The General Status of Alberta Wild Species 2000*), and 2005 (*The General Status of Alberta Wild Species 2005*) assign individual species "ranks" that reflect the perceived level of risk to populations that occur in the province. Such designations are determined from extensive consultations with professional and amateur biologists, and from a variety of readily available sources of population data. A key objective of these reviews is to identify species that may be considered for more detailed status determinations.

The Alberta Wildlife Status Report Series is an extension of the general status exercise, and provides comprehensive current summaries of the biological status of selected wildlife species in Alberta. Priority is given to species that are *At Risk* or *May Be At Risk* in the province, that are of uncertain status (*Undetermined*), or that are considered to be at risk at a national level by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Reports in this series are published and distributed by the Alberta Conservation Association and the Fish and Wildlife Division of Alberta Sustainable Resource Development. They are intended to provide detailed and up-to-date information that will be useful to resource professionals for managing populations of species and their habitats in the province. The reports are also designed to provide current information that will assist Alberta's Endangered Species Conservation Committee in identifying species that may be formally designated as *Endangered* or *Threatened* under Alberta's *Wildlife Act*. To achieve these goals, the reports have been authored and/or reviewed by individuals with unique local expertise in the biology and management of each species.

EXECUTIVE SUMMARY

The Athabasca rainbow trout (*Oncorhynchus mykiss*) refers to a complex of populations that are native to Alberta waters and are confined to the upper Athabasca River and its tributaries, including the McLeod, Berland/Wildhay, and Freeman rivers and their headwater streams. The biology of the native Athabasca rainbow trout differs from that of introduced rainbow trout, which are abundant in southern Alberta, in that the native trout spawn later in the spring, grow much more slowly, and mature at a smaller size than their introduced counterparts. The native rainbow trout appear to be better adapted to cold, unproductive headwater environments than introduced varieties. Genetic studies using microsatellite DNA show that the populations in the above-mentioned river systems are often distinct from one another; however, the Athabasca rainbow trout as a group are not phylogenetically distinct from upper Fraser River populations in neighbouring British Columbia. It is likely that Athabasca populations originated as a result of headwater transfer across the continental divide at the close of the last ice age. Athabasca rainbow trout are not considered to be a distinct subspecies, but qualify as a "designatable unit" (DU) below the species level according to guidelines of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), based on occupancy of a biogeographic region ("Western Arctic") distinct from all others in Canada.

There is growing concern about indigenous rainbow trout populations, as population densities of the Athabasca rainbow trout in their native streams are much lower than those encountered in early surveys of the area. Potential limiting factors include natural disturbances such as extreme floods, and watershed disturbances caused by forest fires and land-use practices such as logging and mining. In addition, the accelerated pace of road building, together with hydroelectric and natural gas rights-of-way and associated bridges and culverts, can degrade the habitat of the rainbow trout. The potential impacts of anthropogenic climate change, and changes in the watershed as a result of mountain pine beetle infestations, for example, may also pose a threat. Recreational fishing is also a serious limiting factor, and the populations that have best maintained their abundance have been closed to angling for several decades. Another potentially serious limiting factor is competition with introduced brook trout (*Salvelinus fontinalis*) that were stocked into many of the region's streams and are spreading and becoming more abundant. Measures aimed at removal or mitigation of brook trout should be considered. In addition, there is concern about the possible effects of introgression with introduced hatchery rainbow trout, which were stocked into many streams and lakes in this region.

Native stocks of rainbow trout within the Athabasca River are considered *May Be At Risk* by the *General Status of Alberta Wild Species 2005* report. They are presently managed under the Eastern Slopes Zone 1 (watershed unit ES3) fishing regulations, which, in many streams, still allow these fish to be retained albeit with very restrictive limits. The possibility of restricting angling even further, and imposing "catch-and-release" practices, should be considered, since it would likely improve the viability of the small stream populations of these native rainbow trout.

ACKNOWLEDGEMENTS

We would like to thank George Sterling (Alberta Sustainable Resource Development [ASRD], Edson) for his help in the preparation of this report. He carried out detailed searches of the Fisheries Management Information System (FMIS) database for all data pertaining to Athabasca rainbow trout, as well as introduced brook trout in the Athabasca region, and supplied us with the data files that we analyzed for this report, as well as the map shown in Figure 1. In addition, George provided the historical context for all of the analysis, by virtue of his long experience and deep knowledge of the Athabasca region and its fish resources. He also took the time to perform a thorough review of the manuscript. We would also like to thank Dr. Michael Sullivan (ASRD, Edmonton) for his contributions to the risk assessments that were carried out in this analysis. Lisa Matthias (ASRD, Edmonton), Sue Peters (Alberta Conservation Association, Edmonton) and Craig Johnson (ASRD, Grande Prairie) reviewed the manuscript and provided helpful suggestions and comments. Anke Bezeidenhout (University of Lethbridge) was very helpful in preparing and analyzing the data files used in this analysis, and Lucas Rasmussen read over the manuscript and provided considerable editorial assistance. Ngaio Baril (Foothills Stream Crossing Program [FSCP], Foothills Research Institute, Hinton) provided a summary of the FSCP data for crossings that are high risk for fish passage.

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INTRODUCTION

The geographic distribution of indigenous rainbow trout (*Oncorhynchus mykiss*) in North America is confined mainly to west coast drainage systems, and only three rivers east of the continental divide are known to harbour native populations: the Peace, the Liard, and the Athabasca rivers. All three of these drain to the Arctic Ocean, and among these, the Athabasca complex of populations is the only rainbow trout native to Alberta waters. These native rainbow trout are confined to the upper Athabasca River and its tributaries, the McLeod, the Berland/Wildhay, and the Freeman rivers, and their headwater streams. The localized distribution of native rainbow trout in Alberta is in contrast to the widespread introduction of *O. mykiss* from a variety of non-native source populations in the Peace, Bow, North and South Saskatchewan and Athabasca rivers in Alberta.

There has been growing concern about Alberta's native rainbow trout populations, as numbers may be declining in some areas as a result of habitat loss and degradation associated with logging activities, sedimentation associated with roads and exploration rights-of-way, or other anthropogenic stresses such as the effects of selenium from coal mining, recreational fishing, and introgression with non-native trout (Holm et al. 2005, Taylor et al. 2007, Park et al. 2008). The potential impacts of anthropogenic climate change and associated changes in the watershed may also pose a threat. The *General Status of Alberta Wild Species 2005* ranks Athabasca rainbow trout as *May Be At Risk** (Alberta Sustainable Resource Development 2007). At the time of this report, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) had not conducted a status assessment for rainbow trout in Canada; however, it was on their list of high priority candidate species for assessment (COSEWIC 2008). This report summarizes current information available on native rainbow trout in Alberta, and is an important step in updating its status in the province.

* See Appendix 1 for definitions of selected status designations.

SPECIES TAXONOMY

1. Species Description and Identification. - The Athabasca rainbow trout has the streamlined body shape typical of salmonid fishes; a full morphological description is given in Nelson and Paetz (1992). Rainbow trout are bluish-green on the dorsal surface and silvery to yellowish-green on the sides. The dorsal surface is covered in dark spots that extend to the fins and the lateral surface, typically to the level of the pectoral and pelvic fins. Spawning fish usually have a pronounced red lateral band, especially in the males. The juveniles have 8 to 10 oval black "parr marks" along the lateral surface that can be retained in headwater populations that mature at small sizes (less than 20 cm total length). Overall, Behnke (1992) considered Alberta rainbow trout to be morphologically similar to interior "redband trout" native to the upper Columbia and Fraser rivers (although he also suggested that Athabasca rainbow trout had lower scale counts than Columbia/Fraser redband rainbow trout). Rainbow trout are typically distinguished from westslope cutthrout trout (*O. clarkii lewisi*) (which, although native to only the Bow and South Saskatchewan rivers in southern Alberta, have been introduced into the native range of Athabasca rainbow trout; see Nelson and Paetz 1992, page 259) by a lack of basibranchial teeth and the lack of a red slash under the upper jaw, both of which are present in *O. c. lewisi*. Although the largest rainbow trout ever recorded in Alberta was over 87 cm in length (Nelson and Paetz 1992), this was from an introduced population. Most native rainbow trout mature at much smaller sizes (30 cm - 45 cm) and fish from the Tri-Creeks area (McLeod River drainage) may be as small as 10 g in weight and 52 mm long at two years

of age (Nelson and Paetz 1992). Rainbow trout grow very slowly in the streams of the Athabasca region and first spawn between three and four years of age (Nelson and Paetz 1992).

2. Taxonomic Issues. - Taxonomic investigations within *O. mykiss* have a long history and are summarized in Behnke (1992). Within the species, Behnke (1992) has recognized six subspecies, of which the "redband" trout (*O. m. gairdneri*) of northern interior basins of North America and coastal rainbow trout (*O. m. irideus*) are the most widely distributed. The phylogenetic distinctiveness of the Athabasca River populations of rainbow trout has been controversial, and as a result it has not always been clear what separate taxonomic status (if any) they should be accorded. Bajkov (1927), who first described rainbow trout from the Athabasca River from collections made in Jasper National Park, identified them as *Salmo irideus* and considered them morphologically distinct from the typical rainbow trout, which he referred to as *Salmo gairdneri*. On the basis of morphometric characters, allozyme evidence and chromosome counts, Behnke (1992) hypothesized that Athabasca River populations originated from the Columbia River redband trout (*O. m. gairdneri*), which he thought had invaded the Fraser River post-glacially from a Pacific glacial refugium in the lower Columbia River area. From the upper Fraser River these fish are thought to have gained access to the upper Athabasca River through the Yellowhead pass, via watershed transfer from the upper Fraser (McPhail and Lindsey 1986). This view places the Athabasca populations at a similar level of distinctiveness as some B.C. headwater populations; therefore, Behnke (1992), in his review of western trout, considered Athabasca rainbow trout to be part of the *Oncorhynchus mykiss gairdneri* subspecies ("redband trout" of the upper Columbia River and adjacent basins). On the other hand, Carl et al. (1994) argued that the Athabasca rainbow trout was both morphologically and genetically distinct from other redband rainbow trout. They also suggested that Athabasca rainbow trout represent a pre-glacial relict that became separated from rainbow trout west of the continental divide as much as 60 000 years ago, as a result of isolation and survival during the last glaciation in a distinctive Alberta refugium. If this view is correct, these fish should be considered a distinct subspecies of rainbow trout (i.e., separate from *O. m. gairdneri*). In fact, Nelson and Paetz (1992) argued that the native Athabasca rainbow trout should be afforded special protection because they may be taxonomically unique.

By contrast, McCusker et al. (2000) examined mitochondrial DNA of 10 fish from the Athabasca River drainage (Wampus, Cabin, and Halpenny creeks) and found them to be *identical* to haplotypes in the adjacent upper Fraser River. These genetic data strongly support the hypothesis put forward by previous authors (Behnke 1992, Nelson and Paetz 1992), that rainbow trout invaded the Athabasca River at the end of the last ice age (circa 10 000 years ago) via headwater transfer from the upper Fraser (McPhail and Lindsey 1986). Further, Taylor et al. (2007) examined allele frequencies at 10 microsatellite loci in fish sampled from tributaries of three different river systems within the Athabasca River region (Athabasca, McLeod and the Wildhay/Berland rivers, see Table 1) and compared them to fish from a number of upper Fraser River tributaries immediately adjacent to the continental divide, plus a number of other BC populations, including anadromous rainbow trout (commonly referred to as "steelhead trout"). Although the microsatellite data showed that a significant fraction of the variance can be attributed to individual river systems of the Athabasca and upper Fraser rivers, Athabasca rainbow trout populations were not, as a group, any more distinctive from adjacent Fraser River headwater populations than were other assemblages of rainbow trout (e.g., coastal steelhead, *O. m. irideus*). These authors, therefore, concluded that Athabasca rainbow trout are of post-glacial origin and do

Table 1. Percentage of hatchery alleles detected in rainbow trout sampled in various water bodies of the Athabasca River system. NA = not applicable.

a) Water bodies with no record of rainbow trout stocking:

Name of water body	Year stocked	Year collected	N	% hatchery alleles
Athabasca River Tributaries:				
Emerson Creek	NA	2000	13	0.0
Oldman Creek	NA	2000	10	0.0
Lynx Creek	NA	2000	10	0.0
Windfall Creek	NA	2000	14	0.0
Pine Creek	NA	2000	4	0.0
Sakawatamau River	NA	2000	5	0.0
Buffalo Prairie	NA	2002	40	0.0
McLeod River Tributaries:				
Felton Creek	NA	2000	10	0.0
Deerlick Creek	NA	2000	10	0.0
Anderson Creek	NA	2000	25	0.0
Wampus Creek	NA	2004	20	0.0
Wildhay/Berland River and Tributaries:				
Wildhay/Berland River	NA	2000	10	0.0
Hightower Creek	NA	2000	10	0.0
Barbara Creek	NA	2000	10	0.0
Moberly Creek	NA	2000	4	0.0
Cabin Creek	NA	2004	20	0.0
Jessie Creek	NA	2004	20	0.0

(Table 1 continued)

b) Water bodies with populations supplemented by stocking:

Name of water body	Year stocked	Year collected	N	% hatchery alleles
Athabasca River and Tributaries:				
Athabasca River	1950–1952	2000	10	0.0
Two Creeks	1985	2000	10	0.0
Fish Creek	1940	2000	10	0.0
Katy Creek	1952	2000	10	0.0
Chickadee Creek	1985	2000	13	0.0
Sandstone Creek	1985	2000	10	0.0
Canyon Creek	1985–1988	2000	4	0.0
Wabasso Creek	1925, 1951	2003	41	4.8
Lac Beauvert	1950–1952	2003	34	41.0
Tekarra Creek	1941–1956	2003	5	0.0
Cottonwood Creek	1947	2003	40	43.0
McLeod River Tributaries:				
Moose Creek	1928–1940	2000	10	0.0
Luscar Creek	1934	2000	17	0.0
White Creek	1953	2000	10	0.0
McKenzie Creek	1935–1936	2000	10.0	0.0
Edson River	1926–1953	2000	10.0	0.0
Trout Creek	1926–1947	2000	24	0.0
Mitchell Creek	1932–1934	2000	1	0.0
Prest Creek	1935–1953	2000	3	0.0
Lac des Roches	?	2000	36	0.0
Wildhay/Berland Tributaries:				
Rainbow Lake	1985–1997	2000	11	100.0
Muskeg River	1970–2004	2004	17	65.0
Harvey Lake	1962, 1967	2003	36	100.0

not represent pre-glacial relicts, as had been suggested by Carl et al. (1994). Taken together, the data of McCusker et al. (2000) and Taylor et al. (2007) cast considerable doubt on the validity of any separate taxonomic designation for Alberta populations. In addition, McCusker et al. (2000) suggested that some of the genetic distinctiveness of Athabasca rainbow trout reported by Carl et al. (1994) resulted from hybridization with introduced cutthroat trout. Several of the alleles found to distinguish Wampus Creek rainbow trout from other rainbow trout were present at high frequency in coastal cutthroat trout, *O. clarkii clarkii*, from Puget Sound, especially for the *PEPA*-110 allele (Campton and Utter 1987, McCusker 1999).

In summary, there is no strong evidence that Athabasca rainbow trout constitute a taxon distinctive from that originally proposed by Behnke (1992); in other words, these populations represent *O. m. gairdneri* that have become isolated post-glacially from the main range of the subspecies in the upper Columbia and Fraser rivers.

HABITAT

Athabasca rainbow trout live primarily in cold headwater streams and a few lakes of the Athabasca region of Alberta. Although they are found in the larger rivers of the region, they are most numerous in 2nd to 4th order streams that are only a few metres wide. The most favourable streams are those that remain cool during summer, are well-oxygenated, and have sufficient fine gravel (1 cm - 5 cm rocks) that is free of fine sediment for spawning.

The biology of the native Athabasca rainbow trout differs in many ways from that of introduced rainbow trout, which are abundant in southern Alberta. The native trout spawn later in the spring (late May-June versus late April-May) using finer gravels, grow more slowly, and mature at a smaller size than their introduced counterparts (Dietz 1971; Sterling 1990; Nelson and Paetz 1992). It is not uncommon for spawning adult Athabasca rainbow trout to weigh less than 50 g, and Nelson and Paetz (1992) suggest that they may be the slowest growing rainbow trout in the world. The native rainbow trout appear to be better adapted to cold, unproductive headwater environments than introduced varieties, and this unique habitat is likely the main contributing factor to their unique biological attributes. These rainbow trout feed primarily on both aquatic and terrestrial insects in streams, like most other Alberta stream rainbow trout, and spawn in clean stream gravels. Although native rainbow trout are most commonly found in streams and rivers, they have also been experimentally introduced to several small productive headwater lakes, where feeding conditions permit higher growth rates (Sterling 1989, G. Sterling, pers. comm.). Lake spawning in these fish has never been recorded. The lake populations of rainbow trout within the range of the Athabasca rainbow trout are introduced hatchery strains.

The habitat of the Athabasca rainbow trout has been affected by human impacts such as logging and the building of roads and cutlines, together with natural processes such as major floods; however, the most dramatic and irreversible trend toward decline in habitat quality has been an increasing loss of headwater stream habitat in some of the tributaries of the McLeod River as a result of open pit coal mining. Factors affecting Athabasca rainbow trout habitat will be discussed further in the Limiting Factors section.

CONSERVATION BIOLOGY

Three important issues in salmonid conservation are: (1) the identification of conservation units below the species level, for example "evolutionarily significant units" (ESU), in order to preserve the evolutionary potential of taxa; (2) evaluating the potential impacts of hatchery supplementation on the gene pools of native

populations; and (3) resolution of population structure of native populations (Allendorf and Waples 1996, Taylor et al. 2007).

1. The Conservation Unit. - A growing array of genetic techniques is being applied in conservation biology to assess the phylogenetic distinctiveness of threatened populations (Morris et al. 1996, Crandall et al. 2000, Schwartz et al. 2007). The concept of the Evolutionarily Significant Unit (ESU), although still not easily operationally defined, has become an integral part of the conservation and management strategy applied to salmonids and many other species, particularly in the United States (e.g., Ryder 1986, Busby et al. 1996). The ESU concept reflects the implicit recognition that some populations can be supplanted or supplemented from neighbouring populations within the *same* ESU, whereas, supplementation using populations from different ESUs is not recommended. In Canada, the idea of distinct ESUs within species is represented by a related concept that recognizes distinctive assemblages of populations within species based on taxonomy, genetics, distinctive and adaptive traits, and biogeography. Such assemblages within species are called "designatable units" (DUs; COSEWIC 2004). DUs within species are assessed for their conservation status separately, and individual DUs may be listed in various categories including *Threatened* or *Endangered* under Canada's Species at Risk Act (SARA); taxa below the species level can also be assessed and listed at the provincial level under Alberta's *Wildlife Act*.

The postglacial origin of Athabasca River rainbow trout and the lack of support for their taxonomic distinctiveness (discussed above) does not reduce their conservation status. For instance, the Athabasca River assemblage of populations is one of only three such assemblages (the others being those in the headwaters of the Peace and Liard rivers) that occupy rivers that drain the east slopes of the Rocky Mountains and flow to the Arctic watershed (Behnke 1992). In addition, the Athabasca River populations have, by far, the more extensive distributions within these eastward-flowing drainages (McPhail and Lindsey 1970; Behnke 1992). Consequently, the Athabasca River rainbow trout are found in the "Western Arctic" freshwater aquatic biogeographic regions in Canada, one of 14 such regions recognized by COSEWIC (2004). Occupancy in distinctive biogeographic regions is one of the criteria used to establish DUs (at or below the species level) for conservation status review and potential listing under SARA (COSEWIC 2004; Taylor 2006).

2. The Integrity of the Native Genome.- Hybridization and genetic introgression between native and introduced salmonid taxa have been recognized for some time as serious conservation issues in western North America (Leary et al. 1995). Several studies have documented genetic introgression between introduced hatchery rainbow trout and native westslope cutthroat trout (e.g., Allendorf et al. 2001; Rubidge and Taylor 2005), including areas in Alberta (e.g., Taylor and Gow 2007; Robinson et al. in prep). Currently, however, there is no general or common approach for management of hybrids, setting conservation priorities that recognize the existence of hybrids, or conserving the integrity of native genomes (Allendorf et al. 2005). Athabasca rainbow trout populations have been subject to supplementation of hatchery rainbow trout from a diversity of sources since the early 1920s (G. Sterling, unpubl. data). In addition to overharvest, and habitat loss and degradation, introgression with introduced genotypes was thought (by Nelson and Paetz 1992) to have contributed to the decline of native rainbow trout in the Athabasca region.

In addition to the previously mentioned microsatellite analysis on fish from tributaries of the Athabasca, McLeod and Wildhay/Berland river systems, several hatchery populations were also sampled (Beity/Beaver and Mount

Lassen populations). The analysis carried out by Taylor et al. (2007) showed that there has been little detectable genetic introgression of hatchery rainbow trout alleles into most of the Alberta populations that have received introductions of hatchery fish (Table 1). Allele frequencies were markedly different between samples collected from streams subject to stocking and putative source hatchery samples. Samples from stocked streams more closely resembled indigenous trout, and over 99% of the wild-collected trout that had experienced no known hatchery supplementation were assigned as "native" trout. By contrast, up to 21% of wild-collected trout that had experienced some hatchery supplementation were assigned to the "hatchery" group rather than the "native" grouping. Almost half of these fish (37/80) came from lake populations (Harvey and Rainbow lakes; see Table 1), and all of the Harvey Lake fish (36) were assigned to the hatchery category. Harvey Lake was fishless before it was stocked between 1962 and 1967 and these data indicate that a self-sustaining population has become established in the lake. Only two streams, Cottonwood Creek and Muskeg River, had appreciable numbers of wild-collected trout assigned to the hatchery grouping. Interestingly, Muskeg River is part of the Smoky River drainage that has no known indigenous populations of *O. mykiss* (G. Sterling, unpubl. data). The Muskeg River is, therefore, one of the few localities in the genetic survey that are known to have been colonized by hatchery fish introduced into adjacent watersheds. Although the river itself has not been supplemented, a complex of small lakes just upstream (Pierre Greys Lakes) was stocked repeatedly beginning in 1970 and most recently in 2004 (G. Sterling, unpubl. data). Consequently, the presence of hatchery genotypes within the Muskeg River samples probably stems from downstream dispersal of hatchery fish from these lake sources (Rubidge and Taylor 2005).

3. Population Structure. - The level of genetic differentiation among native populations of Athabasca rainbow trout (i.e., their degree of population structure) is a critical component of a comprehensive conservation genetic strategy. A high degree of population structure, as measured by differentiation in molecular genetic traits, is often strongly associated with independence among populations in demographic parameters important to persistence in different environments (e.g., migration between environments, abundance and population growth rates, survival, maturity schedules; Palsbøll et al. 2007, Schwartz et al. 2007). Such demographic independence inferred from genetic data implies that it may be appropriate to individually assess the conservation status of each of the populations separately and that population-specific management regimes may need to be designed to ensure persistence of a species across a range of habitat.

In the analysis of Taylor et al. (2007), genetic differentiation among populations was summarized using the statistic F_{ST}, which is the proportion of the total genetic variability that is attributable to differences between populations. The values of F_{ST} calculated among Alberta populations averaged 0.13 and were highly statistically significant. Forty of the 51 possible pairwise comparisons of allele frequencies among non-hatchery-influenced populations were statistically significant, indicating a high level of population structure in Athabasca rainbow trout. The F_{ST} value of 0.13 is comparable to (but still lower than) values of 0.18 for native rainbow trout in the Lakes' region of BC, but lower than a value of 0.39 reported for rainbow trout across their entire range in BC (Taylor et al. 2007). Although these data clearly imply some restriction to dispersal and gene flow among streams, they also suggested that there is detectable dispersal by fish among streams over the recent past (a few generations), and that such movements vary depending on the specific streams being

considered. Consequently, although there is significant genetic differentiation among Athabasca rainbow trout populations, such isolation is not complete and it is possible that specific populations may act as sources of fish that could assist in the recovery of other populations that have experienced demographic declines. The significant genetic subdivision within Athabasca rainbow trout suggests that efforts to design management programs should be made on a watershed-by-watershed basis with specific emphasis on the potential for natural levels of exchange among populations within watersheds. For instance, upstream portions of watersheds may be less likely to be re-colonized than downstream areas (e.g., Gotelli and Taylor 1999).

DISTRIBUTION

Athabasca rainbow trout are distributed throughout the headwaters of the Athabasca River system, with an extent of occurrence of between 19 100 km^2 (using a convex hull polygon) and 21 000 km^2. This range includes the Athabasca River itself, as well as its major tributaries, including the McLeod, the Wildhay/Berland, the Sakwatamau and the Freeman rivers (Figure 1). Populations can be found downstream as far as the Freeman River. The range includes significant portions of Jasper National Park (Ward 1974), including the mainstem Athabasca River watershed downstream of Sunwapta Falls, and the lower reaches of the Snaring, Maligne, Rocky and Snake Indian river systems downstream of major waterfalls, and the majority of the Miette River watershed, through which rainbow trout likely entered Alberta from British Columbia. This is the same range reported by Miller and Macdonald (1949), and Nelson and Paetz (1992). Although rainbow trout have been stocked to streams in the upper Pembina River system, no native Athabasca rainbow trout populations are known from this portion of the Athabasca system, or from the lower portions of the McLeod or Freeman rivers. Rainbow trout have also been stocked into the tributaries of the Peace River, but no native populations are known from the Alberta portion of the Peace River system. The area within its range that is occupied by this species (i.e., area of occupancy), calculated using a 2-km x 2-km grid, is approximately 1332 km^2.

POPULATION SIZE AND TRENDS

Miller and Macdonald (1949) were the first to survey the fisheries resources of the Athabasca River region. Many of the creeks and rivers that they surveyed, especially those of the McLeod drainage had abundant populations of Arctic grayling and stunted rainbow trout, whose small size and slow growth they attributed to the cold temperatures and overall low stream productivity. Similar observations have been made by fishermen, who visited these streams during the 1950s and 1960s, before the area was opened up by roads and gas and power rights-of-way to the extent that it is now. Miller and Macdonald (1949) devalued the fisheries potential of the region, mainly because of the small size of the fish (adult fish were approximately 1 oz) that they encountered in most of the streams; however, the enormous fish abundance stood in stark contrast to their small size and growth rate. Although there still are some streams in the region that exhibit densities of the level of abundance that Miller and Macdonald encountered, there is little doubt that many changes have taken place in the fish fauna. Arctic grayling (*Thymallus arcticus*), a *Species of Special Concern* in Alberta, are now virtually absent from most streams and rivers in the Athabasca region. The rainbow trout, even though they remain as small and slow-growing as ever, appear to be much less abundant overall than they were 50 years ago (G. Sterling, pers. comm.). At the time of the Miller and Macdonald (1949) survey, coal mining activities in the Mercoal area were already well established and the survey reported that habitat conditions in Luscar Creek were degraded as a result of siltation and bank erosion, and that few fish were present.

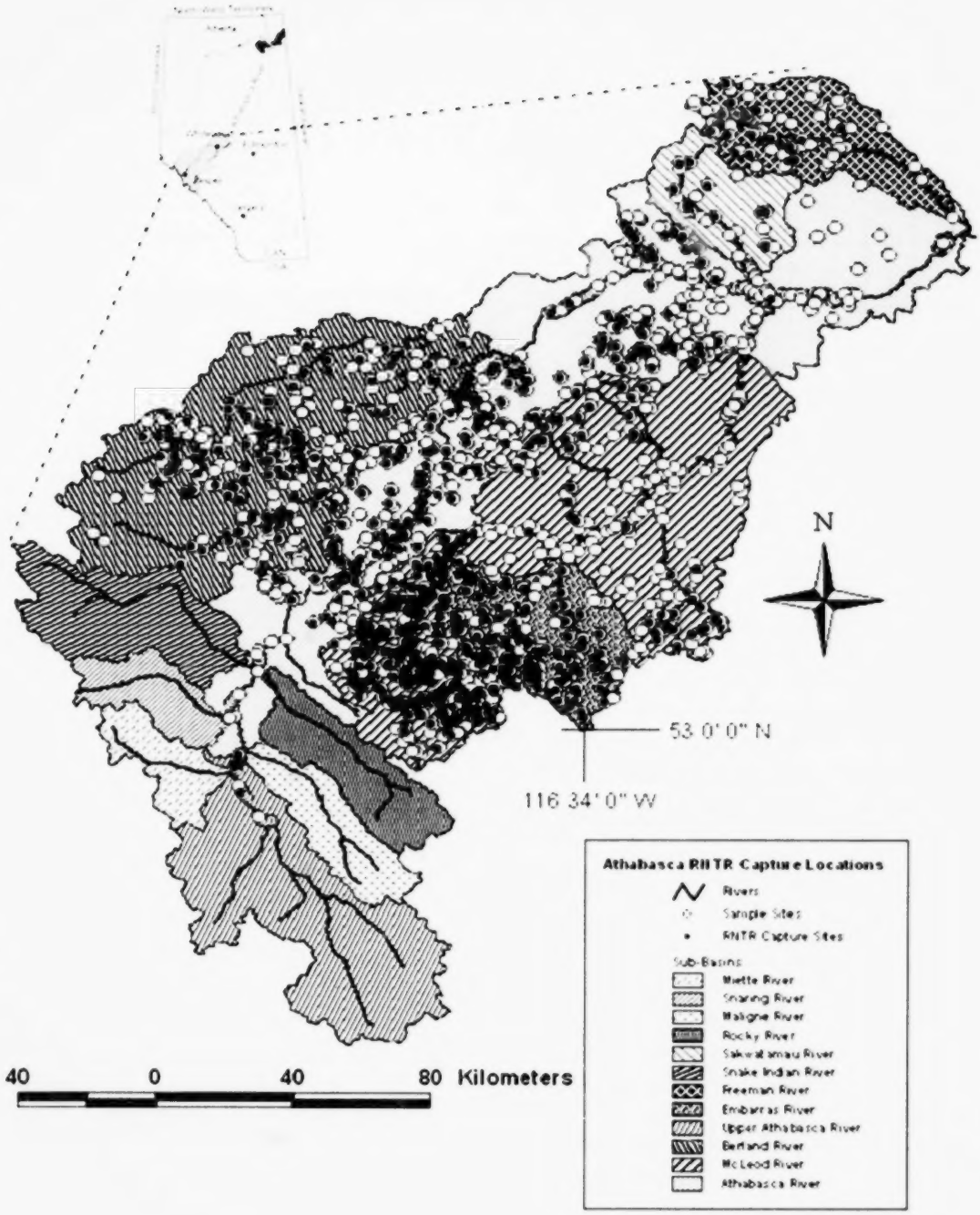


Figure 1. Map of the Athabasca River and its watershed within Alberta, outlining sub-watershed boundaries, encompassing the entire range of the Athabasca rainbow trout. Each dot represents a sampling record within the Fisheries Management Information System (FMIS) data base (supported by the Fish and Wildlife Division, ASRD); black dots represent rainbow trout capture locations, and white dots represent locations where they were not recorded. Most Jasper National Park sampling records are not contained within the FMIS data base and are not included on this map. Major contributors to the FMIS data base are the Alberta Conservation Association (ACA), the Foothills Research Institute (Hinton, AB), and Alberta's Fish and Wildlife Division.

1. Assessment of Demographic Risk. - It is difficult to estimate rates of decline in a way that can be used by Alberta's Endangered Species Conservation Committee and Scientific Subcommittee to assess biological status. Comprehensive sampling programs aimed at estimating total population abundance over time and stratified with respect to the different rivers systems and stream orders present, and sufficiently intense to average over the huge temporal variability of local abundances, would have to have been in effect in the Upper Athabasca River system. Although sampling has been carried out in many streams, covering much of this area over the last three decades, the sampling objectives have been to answer questions pertaining to the management of individual streams. These individual streams change over time, and, therefore, no consistent, stratified sampling program for the whole Alberta population has been in effect. The only quantitative sampling of sufficient intensity to quantify temporal fluctuations has been done in two creeks (Wampus and Deerlick) of the Tri-Creeks Experimental Watershed (TCEW) (Figure 2). Beyond that, spatial and temporal coverage has been spotty, even though many streams have been sampled. In addition to this, the early fisheries surveys of the area (Miller and Macdonald 1949) were limited in scope and only semi-quantitative.

Post et al. (2002) made use of unharvested benchmarks rather than time trajectories for assessing the collapse of recreational fisheries in Alberta and across Canada. They show that populations reduced by 80% relative to such benchmarks, are at high risk and rarely recover as a result of a series of depensatory factors (density-dependent factors that slow the rate of population growth at low densities). Such responses can result from food web shifts, including the proliferation of competitors that block or delay recovery and can place populations at serious risk, or from a series of management failures (Sullivan 2002, 2003a, b). Even though their approach was applied to individual fisheries rather than species populations, and as such does not explicitly address risk to whole species, it can be practically applied in situations where the database is too incomplete to allow the estimation of time trends for whole populations. In recent years, this approach to risk assessment, employing thresholds of 50% and 80% reduction relative to unharvested benchmarks, has been applied to a number of recreational fisheries management problems in Alberta with considerable success (M. Sullivan, pers. comm.). In order to provide a picture of the status of the whole population in a region, the proportions of streams, rivers, or lakes within each risk category can then be estimated, and the likelihood that widespread fisheries collapses put the species at risk within the area of concern can be assessed (Sullivan 2003a, b). Although this approach is analogous to the IUCN approach in that it considers similar quantitative thresholds for its risk categories, it is different in that it is not definitively tied to a time trend, it is applied to individual fisheries rather than species population, and it is systemically based and empirical rather than based on demographic population models.

Benchmarks can be established using data from unharvested streams, rivers or lakes, or by population or catch-per-unit effort estimates from historical sources (Sullivan 2003a, b; Valastin and Sullivan 1997). The TCEW streams south of Hinton have been closed to recreational fishing for the last 40 years and include two creeks, Wampus and Deerlick, that have been sampled fairly consistently during this period by personnel from ASRD and other agencies. Although the natural variability of rainbow trout abundance in these streams is very great (Figure 2), mostly as a result of major flood events, abundance usually exceeds 100 fish/0.1 ha and rarely dips as low as 50 fish/ 0.1ha. Furthermore, abundance levels over the 40-year period show a consistent pattern of rapid recovery within a few years from the combined impacts of logging and severe floods.

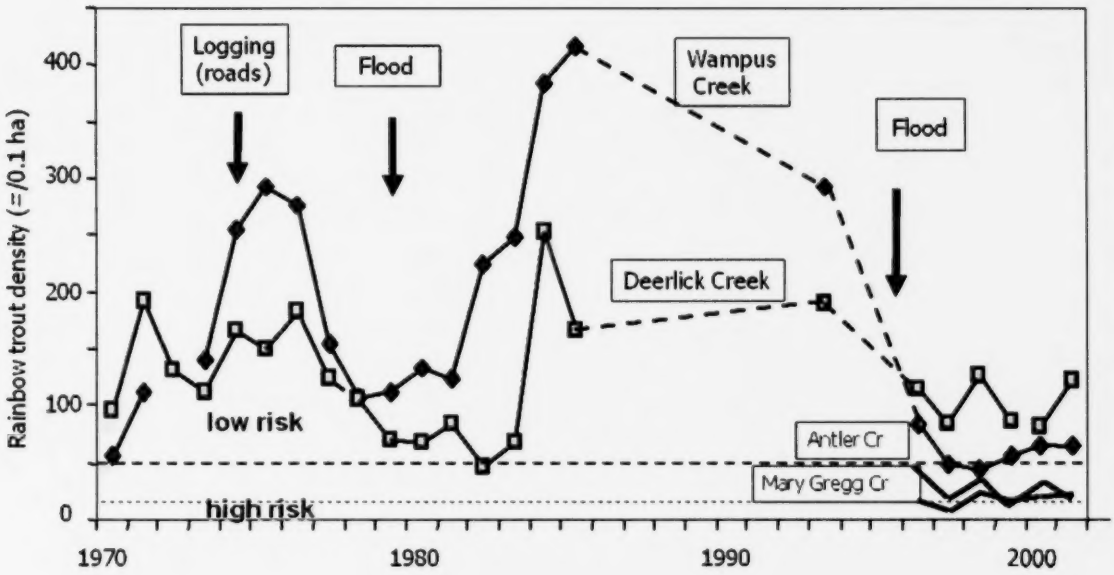


Figure 2: Risk thresholds for Athabasca rainbow trout based on IUCN criteria of 50% (----) and 80% (·····) decline from the undisturbed benchmark. This benchmark value was estimated to be 100 fish/0.1ha, based on long-term records for two reference creeks, Wampus and Deerlick. Mary Gregg and Antler creeks have been open to fishing and have abundance levels below the 50% threshold (20-50 fish/0.1 ha). Population estimates were derived from permanent sampling plots (300 m -1000 m) in the lower reaches of each study stream. Estimates from 1970 to 1985 were obtained by G. Sterling using the mark-recapture technique; those from 1993 onward were obtained by C. Johnson using the depletion-removal technique. The differences between the estimates obtained by the two techniques are not large enough to have affected the placement of risk thresholds. Points between 1985 and 1996 at Wampus and Deerlick creeks are connected by dashed lines (large dash) because of the sparse data during this interval.

In contrast to the unharvested streams, Mary Gregg and Antler creeks, which were exposed to both recreational fishing as well as some land-use impacts (including a coal mine on a tributary to Mary Gregg Creek and some logging in the Antler Creek watershed), have rainbow trout abundances that fluctuated within the range of 20-50 fish/0.1 ha. Thus, using a benchmark of 100 fish/0.1 ha, a 50% reduction threshold for moderate risk, and an 80% threshold for high risk was established. The data for Wampus and Deerlick creeks indicate that a level of abundance greater than 50 fish/0.1 ha would likely provide resilience against abiotic stresses such as major flood events, and likely also biotic factors such as competition from exotic species like the brook trout. This level of abundance is consistent with levels of salmonid abundance observed in unimpacted boreal streams in Canada (e.g., Tucker and Rasmussen 1999, Morinville and Rasmussen 2003). We therefore considered streams with abundance levels greater than 50 fish/0.1 ha to be in the low risk category.

Populations with abundance levels less than 20 fish/0.1 ha are considered high risk, and are likely highly vulnerable to depensatory factors that can inhibit population recovery and will likely remain dependent on immigration of trout from the main river systems to sustain them over the long term. Abundance levels

within this range could reflect either naturally very poor or degraded habitat conditions, and would likely have reduced resilience against, and slow recovery from, abiotic environmental stresses such as major floods, or anthropogenic stresses from mining and clear-cutting and other activities. Such populations can also be expected to be highly vulnerable to biotic stresses, since the low population densities characteristic of this group of streams means that there is a considerable amount of open habitat space. Thus, exotic invaders such as brook trout, or introduced strains of rainbow and cutthroat trout, could become established with minimal competitive resistance from native rainbow trout.

Finally, streams with abundance levels in the 20-50 fish/0.1 ha range were considered to be in the moderate risk category. These were considered either to have been impacted by land-use or other stress factors or else to have suboptimal habitat conditions. Such populations would likely have reduced resilience against natural and anthropogenic stresses, and perhaps some impaired capacity for recovery, but to a lesser extent than those in the high risk category.

Based on rough estimates and area-density calculations, M. G. Sullivan (pers. comm.) estimated the total adult population of native rainbow trout in Alberta to be between 15 000 and 25 000 fish.

2. Risk Categorization of Rainbow Trout Streams. - Abundance estimates (number of rainbow trout/0.1ha) for Alberta were compiled using data from the Fish and Wildlife Division (ASRD) Fisheries Management Information System data base (FMIS) for 28 Athabasca mainstem tributaries, 28 Berland/ Wildhay tributaries (including the Berland and Wildhay rivers themselves), 4 Freeman River tributaries, and 62 tributaries to the McLeod River, including the Embarras, Erith and Gregg rivers and their tributaries. Although the estimates spanned the period from 1970-2005, most were made since 1990. Most streams in the Athabasca region were subjected to strong recreational fishing pressure before the Fish and Wildlife Division surveys began, so it is difficult to directly document declining trends in individual populations since these declines likely happened within the first few years of exposure to recreational fishing. However, the breakdown by risk categories based on abundance, does indicate that 54% of the streams for which abundance data could be compiled, fell into the highest risk category, 27% fell into the moderate risk category and only 19% fell into the low risk category (Figure 3). Although this breakdown varied somewhat among the three river systems, the same overall pattern was evident in all three (Figure 3).

LIMITING FACTORS

Natural abiotic stresses such as large flood events, which often occur during June when Athabasca rainbow trout have eggs in the gravel, combined with a series of anthropogenic factors, such as overharvesting, habitat loss and degradation resulting from land use practices, and genetic introgression with introduced genetic strains (see 2. The Integrity of the Native Genome, in the Conservation Biology section) are all factors that could be expected to contribute to the decline of native rainbow trout populations in Alberta. In addition, the potential impacts of anthropogenic climate change as well as watershed changes resulting from mountain pine beetle infestations should also be considered as possible limiting factors. Although many of the headwater streams and rivers that feed the Athabasca River come from Jasper National Park, where the land-use spectrum is fairly restricted, a great deal of the watershed is located outside the Park and is subjected to a wide range of intensive practices that are accelerating rapidly. These include coal mining, logging, oil and gas exploration and refining, and a wide range of agricultural uses. To facilitate these exploitative uses, roads and rights-of-ways are being constructed at an

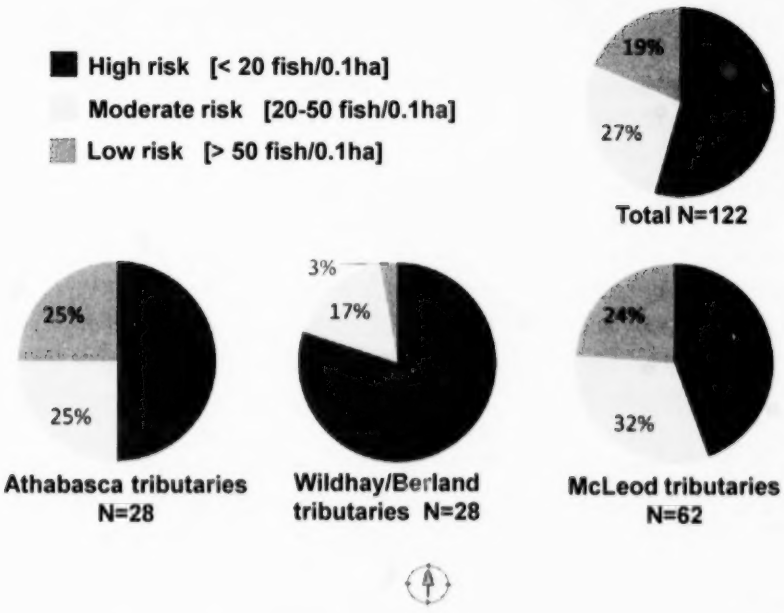
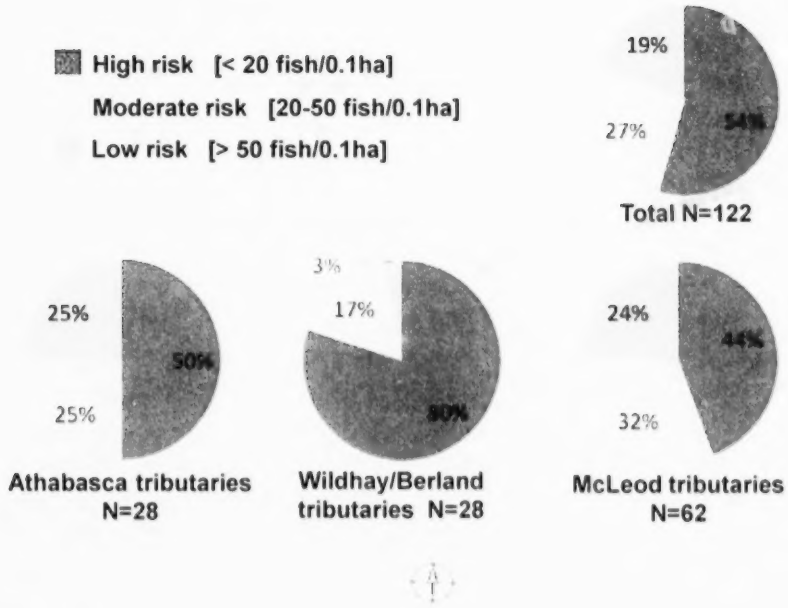


Figure 3. Pie graphs showing the breakdown of streams from different river systems into categories of high, medium and low risk.

accelerating rate; these developments impact streams through erosion and siltation, channel alterations (especially at bridge crossings), and through culvert construction, which contribute to stream fragmentation by restricting upstream movements (Park et al. 2008). The Foothills Stream Crossing Program database indicates that 29% (123 of 427) of streams in the Hinton area that are likely to have Athabasca rainbow trout (i.e., high- and medium-fish-probability streams, based on the model by McCleary and Hassan 2008) have stream crossings that are considered high risk for fish passage (N. Baril, pers. comm.).

Besides opening up the undisturbed habitats for industrial exploitation, roads and rights-of-ways also lead to increased fishing pressure and increased access to recreational vehicles and random camping. For each stream in the data set, we list the major land-use practices that the stream and its watershed have been exposed to over the last few decades (Appendix 2).

1. Recreational Fishing. - Recreational fishing can influence the Athabasca rainbow trout populations in two ways. The first impact is indirect, resulting from management practices that have encouraged the stocking of exotic species and/or strains of fish, such as the brook trout and hatchery rainbow trout. This practice has had both ecological and genetic influences on the rainbow trout, as has been mentioned previously (see 2. The Integrity of the Native Genome, in the Conservation Biology section). The second aspect of recreational fishing is the actual harvesting, which directly influences the populations, and it is of considerable interest in that fishing has not been allowed on three McLeod River tributaries since 1965. These streams, collectively referred to as the Tri-Creeks Experimental Watershed (TCEW), include Wampus Creek, Deerlick Creek, and Eunice Creek, have been surveyed extensively for nearly four decades by Fish and Wildlife Division, Foothills Model Forest, and Alberta



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Conservation Association personnel using backpack electro-fishing gear. The data from their surveys allow us to compare the abundance of rainbow trout in these streams to the broader sample that has been exposed progressively to more and more fishing pressure as the area has been opened up and access has increased (Alberta Sustainable Resource Development 2006).

The FMIS database indicates that streams closed to fishing have maintained higher rainbow trout abundances over time. Two of the three TCEW streams have rainbow trout populations that are among the highest in the entire data set (Table 2, Appendix 2). In spite of its logging history, Wampus Creek has consistently maintained abundances in the range of 100-300 rainbow trout/0.1 ha, and although it has never been stocked with brook trout, it has been invaded by brook trout, like many other McLeod River tributaries. However, brook trout have never exceeded 20% of the trout population in this stream (Table 3b). Overall, Wampus Creek is ranked first among the 123 streams listed in Appendix 2, in terms of rainbow trout abundance level (average 242 ± 67/0.1 ha). Deerlick Creek, which also has a

Table 2. Demographic risk categories for un-fished reference streams compared to streams exposed to recreational fishing under Eastern Slopes Zone 1 (watershed unit ES3) management.

Water body	Fishing permitted (yes or no)	pre-2000	2000-05
Wampus Creek	No	Low Risk	Low Risk
Deerlick Creek	No	Low Risk	Low Risk
Eunice Creek	No	High Risk	High Risk
other McLeod River tributaries		Total 54	Total 30
Low Risk	Yes	11 (24%)	6 (20%)
Moderate Risk		19 (33%)	10 (33%)
High Risk		24 (43%)	14 (47%)
Wildhay/Berland		Total 28	Total 5
Low Risk	Yes	1 (4%)	1 (20%)
Moderate Risk		6 (21%)	2 (40%)
High Risk		21 (75%)	2 (40%)
Athabasca tributaries		Total 26	Total 11
Low Risk	Yes	6 (23%)	5 (45%)
Moderate Risk		6 (23%)	3 (28%)
High Risk		14 (54%)	3 (28%)
Total of fished streams		108	46
Low Risk		18 (17%)	12 (26%)
Moderate Risk		31 (29%)	15 (33%)
High Risk		59 (55%)	19 (41%)

Table 3. Brook trout as a percentage of the trout population over the last four decades in streams stocked with brook trout in the late 1940s compared to unstocked streams. Land-use categories are defined as: M = mining, L = logging.

	% Brook Trout					
	1970s	1980s	1990s	2000-05	Land Use	Recreational Fishing
a) Streams stocked with brook trout (late 1940s):						
Luscar Creek	---	58.5	49.3	69.2	M,L	no
Gregg River	---	---	18.5	54.8	M,L	yes
McLeod River	---	---	45.3	22.9	M,L	yes
Watson Creek	---	60.0	14.9	44.5	L	yes
Baseline Creek	---	---	79.9	---	L	yes
Chance Creek	26.7	---	61.1	---	L	yes
Dummy Creek	---	74.1	---	85.2	L	yes
Fish Creek	---	---	38.9	---	L	yes
Mercoal Creek	0	11.2	16.0	---	M,L	yes
Average	**13.35**	**51.0**	**40.5**	**55.3**		
b) Streams not directly stocked:						
Jarvis Cr.	22.7	10.0	61.8	100.0	M,L	no
Upper Wampus Cr	0.0	0.0	0.3	0.5	L	no
Lower Wampus Cr	0.2	0.4	4.1	17.0	L	no
Eunice Cr	5.6	---	5.4	31.3	L	no
Deerlick Cr	0.5	2.0	18.3	4.9	L	no
Average	**5.8**	**3.1**	**18.0**	**30.7**		

history of logging, has consistently maintained rainbow trout abundance levels not far below those of Wampus Creek. Its overall average, 184 ± 49/0.1 ha, ranks sixth (Appendix 2). Although Deerlick Creek was never stocked with brook trout, it nevertheless has been invaded; however, like Wampus Creek, brook trout abundance levels have remained generally low, not exceeding 20% of the trout population (Table 3b). Thus, in terms of rainbow trout abundance levels, both Wampus and Deerlick creeks have remained high and reasonably stable through time, and still resemble the descriptions provided by Miller and Macdonald (1949) when they first surveyed the tributaries of the McLeod.

Eunice Creek, the third reference stream, is markedly different from the first two, having consistently maintained very low abundance levels of rainbow trout like other streams assigned to the high risk category. This stream runs through glacial lake sediments (clay) and has very little good spawning gravel for rainbow trout (Dietz 1971). In addition, unlike Wampus and Deerlick creeks, Eunice Creek tends to have extensive areas of open water in the lower reaches during winter because of considerably greater groundwater input. Because of this unique feature, Eunice Creek supports a small annual run of bull trout (*Salvelinus confluentus)*, and juvenile bull trout (1-5 years of age) tend to dominate the fish community. Eunice Creek, like Wampus and Deerlick, has never been stocked with brook trout, but has been invaded via the McLeod River. Although brook trout have generally been very rarely encountered in Eunice Creek, since 2000 it has comprised 31% of the trout population (Table 3b). Although Eunice Creek has been logged, sampling records, which extend back several decades, provide no indication that its rainbow trout population was ever anything but very sparse. Therefore, it appears that although closing streams to fishing can help maintain very high levels of rainbow trout abundance where habitat is good, fishing closure appears to do little to offset the effects of poor habitat.

Even though two of the three streams that are closed to fishing are among the best rainbow trout streams in the region (ranked first and sixth), the streams open to fishing and managed under Eastern Slopes Zone 1 (watershed unit ES3) fishing regulations have not fared nearly as well. Of the streams exposed to fishing, between 41% and 55% are placed in the high risk category (Table 2), and most of these have rainbow trout abundance levels less than 10/0.1 ha. Between 29% and 33% of streams are in the moderate risk category, and between 17% and 26% are in the low risk category (Table 2). This pattern has not changed significantly since 1990. Although the analysis does not allow us to directly examine how much of this risk can be directly attributed to fishing (that is, how many of these streams would, like Eunice Creek, have naturally low abundances because of poor habitat), it does suggest that recreational fishing tends to keep populations in the low abundance/high risk category.

2. Logging. - The vast majority of streams in the Athabasca Region have had portions or all of their watersheds logged (Appendix 2). Presently, only MacKenzie, Watson, Mary Gregg and Antler creeks have watersheds unaffected by recent logging activities, although parts of their watersheds were logged many decades ago. However, all of these streams have been exposed to recreational fishing (although the MacKenzie drainage was closed to all angling in 2000), and the effects appear to be mixed. MacKenzie and Little MacKenzie creeks are both in the high risk category, whereas Watson Creek has maintained high rainbow trout abundances and is in the low risk category. Mary Gregg and Antler creeks are both in the moderate risk category. Thus, there are not enough watersheds in the Athabasca region that are free of recent impact, to allow much insight into the effects of logging on Athabasca rainbow trout.

Sterling (1992) examined effects of logging on rainbow trout in TCEW streams. Streams increased in discharge following logging in their watersheds, leading to increases in both siltation and scouring, but without an apparent decline in annual minimum water flow, which is essential to the maintenance of good winter habitat conditions. Nitrate export and stream nitrate levels increased, as did primary productivity, which led to increased growth rates of rainbow trout age classes hatched in the first few years after logging. Effects of logging on abundance were inconclusive, as large flood events (e.g., 1980; Figure 2) obscured any other effects that logging might have had on survival and age structure. In general, the scouring associated with the 1980 flood event contributed to post-logging spawning habitat being better than pre-logging, and this may have enhanced the recovery of the rainbow trout population from this large flood event (Figure 2).

3. Brook Trout and Other Non-native Fish. - Fisheries management practices have also involved intensive stocking of eastern brook trout, and hatchery-reared strains of rainbow trout and cutthroat trout to the water of the upper Athabasca River inside Jasper National Park (Ward 1974). Such introductions began in the early 1900s; however, early records were poorly kept. More recent introductions have been well documented. Fish and Wildlife Division records show that brook trout were first introduced to several streams in the Athabasca River system outside Jasper National Park during the 1940s.

Although there is no possibility of genetic introgression through hybridization with these introduced char, there is nonetheless a very real danger that native rainbow trout will suffer large-scale replacement by brook trout, through interspecific competition.

Brook trout have been stocked into a number of streams and rivers in the Athabasca region, and from these have spread to others and are presently being encountered sporadically throughout the region. Nine streams and rivers stocked with brook trout during the late 1940s have been surveyed several times over the last 35 years (Table 3a). Data on the relative abundance of brook trout and rainbow trout were compiled for a number of streams where brook trout had been surveyed over a period extending a decade or more. The proportion of the trout population made up of brook trout (number of brook trout/number of brook trout plus rainbow trout) was calculated and averaged over samples spanning 1970-79, 1980-89, 1990-99, and 2000-05, to obtain decadal averages. For this analysis, streams that had been directly stocked with brook trout during the late 1940s were compared to streams where no direct stocking had occurred, but had been invaded indirectly. Brook trout in these stocked streams make up approximately half (44%; ranging from 0% - 85%) of the trout population (Table 3a). Although brook trout numbers in individual streams have fluctuated, their overall contribution to the trout population in these stocked streams appears to have remained relatively constant over the last 25 years.

Although there is a tendency (not statistically significant) for brook trout to be most abundant in the streams in which they were directly stocked, they have dispersed into the main river systems and subsequently colonized many tributaries where no stocking occurred. Five of these subsequently colonized streams have been surveyed several times over the last 35 years (Table 3b). In these streams, brook trout were generally infrequently encountered during the 1970s and 1980s, and made up less than 10% of the trout population. Since 1990, their abundance in this set of streams has risen sharply, and at present they represent 31% of the trout population (ranging from 0.5% - 100%; Table 3b). Thus, the streams that have been colonized secondarily appear to have increasing numbers of brook trout, and will likely end up with as many brook trout as the streams that were directly stocked. It therefore

seems likely that the brook trout will eventually invade most of the streams in the region and, although at present it dominates in only a few, it may ultimately pose a serious threat to the native rainbow trout population of the region.

Although we do not have a clear understanding of the biotic interactions between introduced brook trout and the native rainbow trout, the increasing range and abundance of the brook trout make it clear that they are well adapted to life in the streams of the Athabasca region. In fact, they may in some ways be better adapted to the hydrologic conditions in these streams than the native rainbow trout. Brook trout are a fall-spawning species that are extremely well adapted to life in tiny groundwater-fed streams because they are capable of selecting spawning sites with upwelling groundwater that do not freeze over during winter (Curry and Noakes 1995; Blanchfield and Ridgway 1996). Rainbow trout, on the other hand, have eggs in the gravel during June, and are thus more impacted than brook trout by the scouring associated with even minor flood events that frequently occur at that time of year. Brook trout will excavate through silt and mud to find good spawning gravel, and this makes them less vulnerable than most salmonids to land-use activities, such as logging and road-building, which contribute to siltation of stream gravels. Recent studies also indicate that brook trout may be less sensitive to selenium enrichment caused by coal mining than native rainbow trout (Holm et al. 2005). Another aspect of brook trout biology that contributes to their ability to respond to both natural and anthropogenic environmental stressors is their life history, which involves rapid growth in the first two years followed by early maturity, with spawning often occurring at the end of the second year of life. Rainbow trout on the other hand, in addition to growing very slowly in the streams of the Athabasca region, first spawn at three or four years of age (Nelson and Paetz 1992). Therefore, there are a number of reasons to be concerned about the possibility that a combination of natural and anthropogenic stresses may interact and gradually contribute to replacement of the native rainbow trout in Athabasca streams by introduced brook trout.

Notwithstanding the results of Taylor et al. (2007) that indicated little (less than 1%) introgression of hatchery alleles into most wild populations, that study also showed that hatchery trout can establish self-sustaining naturalized populations (Harvey Lake, Rainbow Lake, Muskeg River) that can provide sources for the spread of hatchery genotypes into indigenous populations. In addition, the Wabasso Creek population, considered a prime example of indigenous Athabasca rainbow trout, contained almost 5% hatchery alleles (Taylor et al. 2007). Allendorf et al. (2004) recommended that only populations of westslope cutthroat trout with less than 1% introgression from non-native cutthroat or rainbow trout be considered in assessments of the abundance and distribution of native cutthroat. These points, plus the fact that ASRD remains committed to the stocking of hatchery rainbow trout suggests that the genetic integrity of native Athabasca rainbow is still at some risk from introgression.

4. Anthropogenic Climate Change. - A detailed analysis of projected anthropogenic global climate change and its effects on water temperature regimes in western Alberta is beyond the scope of this report; however, some comments are prudent. Salmonids are "cool-water" fishes, typically with habitat preferences over all life stages of between 8° and 20°C, depending on the species. Rainbow trout typically prefer water temperatures of between 10° and 18°C and have an estimated upper lethal tolerance of 24°C (Scott and Crossman 1998). Because anthropogenic climate change has the potential to influence the future distribution of aquatic species (e.g., Keleher and Rahel 1996, Rosenfeld et al. 2001), some impacts on the distribution of Athabasca rainbow trout can be anticipated. Consequently, some predictive modeling should be initiated, similar to the

kind conducted by Rosenfeld et al. (2001) for montane populations of the chiselmouth (*Acrocheilus alutaceus*) in BC.

STATUS DESIGNATIONS*

The Alberta government has long recognized the existence of Athabasca rainbow trout as a unique native strain (Alberta Ministry of the Environment 1994). The *General Status of Alberta Wild species 2005* assessed the native stocks of rainbow trout within the historical distribution in Alberta (Athabasca River) as *May Be At Risk*, because they have suffered introgression from introduced trout (Alberta Sustainable Resource Development 2007). The general status of introduced stocks of rainbow trout in Alberta is *Secure*. The Alberta Natural Heritage Information Centre ranks rainbow trout as S5 (Alberta Natural Heritage Information Centre 2007b), noting that the S rank reflects the situation in Alberta for the entire population, not just the pure native populations.

Although the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has not yet recommended listing rainbow trout in Canada, this may change in the future, as native rainbow trout east of the continental divide qualify as one or more separate designatable units (DUs) under COSEWIC guidelines (see Conservation Biology section). The very limited distribution of such eastslope rainbow trout may result in their being assigned higher conservation status under COSEWIC (just as has been established for Alberta populations of westslope cutthrout trout).

RECENT MANAGEMENT IN ALBERTA

Athabasca rainbow trout are managed under Eastern Slopes Zone 1 (watershed unit ES3) angling regulations, which have changed gradually over the last several decades from aggregate bag limits of 10 trout with no size limits or bait bans, to decreased aggregate bag limits combined with closed winter seasons in the 1980s. Since the early 1990s much more restrictive fishing regulations have been introduced province-wide, followed by the province-wide barbless hook rule in 2005. In Zone 1, many headwater streams and rivers have been completely closed to angling or had limits of zero trout imposed (catch and release only). In addition, on the streams where aggregate bag limits allow two trout to be kept, there is a minimum size limit (25 cm or 30 cm) intended to prevent the killing of juvenile fish. Furthermore, there are total bait bans in effect on most streams, designed to increase the survival of fish that are released by anglers. Some headwater streams of the McLeod (the TCEW streams: Wampus, Deerlick and Eunice creeks) are closed year round.

Although brook trout are no longer stocked into streams and lakes in the Athabasca region, in recognition of their potential adverse effects on native species, no management measures have been taken to alleviate the potential impact of introduced salmonids. One possible management option is direct removal. In Quirk Creek, on the upper Elbow River, a pilot study was conducted to determine if anglers could decrease the abundance of brook trout and thereby increase bull trout populations (Paul 2000, Post and Paul 2000). This experimental management program is ongoing and is providing useful information on the feasibility of such measures.

In the U.S., the removal of non-native species by electro-fishing and piscicide in areas downstream of the bull trout populations was examined and initial results suggest some success (Buktenica 1997). In another pilot study in Alberta, a special culvert was installed that limited brook trout access to bull trout spawning areas, but allowed bull trout passage

* See Appendix 1 for definitions of selected status designations.

(Brewin 1994, Buktenica 1997). Experimental studies of the feasibility of brook trout removal involving unlimited capture of brook trout should be considered for the Athabasca region, in order to better evaluate these, and perhaps other, management options.

SYNTHESIS

Most populations of Athabasca rainbow trout are presently at low levels of abundance, relative to levels believed to have been present at the time Miller and Macdonald (1949) carried out the first fish surveys in the Athabasca River watershed. Relative to a benchmark of 100 fish/0.1 ha, about half of the streams where recent surveys were conducted have densities less than 20% of this value, and were assessed as high risk. This pattern seems to be region-wide, with the exception of the two TCEW streams, Wampus and Deerlick creeks, which have been closed to recreational fishing for several decades. Abundance levels in these streams are high enough to place them in the low risk category. In order to more clearly define the demographic status of the Athabasca rainbow trout, it is necessary to conduct more rigorous censuses of selected streams in combination with the experimental application of more restrictive fishing regulations to determine whether or not populations in the high risk category can recover if fishing pressure is alleviated. Similar experimental studies aimed at better understanding different logging and mining practices, as well as experimental management studies aimed at developing techniques to eradicate, or at least minimize, the effects of brook trout, would also help provide a clearer picture of how to minimize environmental stresses on the native rainbow trout. Not only would such information help clarify the current status of these fish, but they may also aid in directing salmonid management as a whole.

The problem of managing populations so as to maintain both their viability and genetic uniqueness is a difficult one. It is fortunate that, in spite of a history of stocking hatchery strains of rainbow trout into streams that harbor native populations, there has been a very minimal degree of genetic introgression. This is difficult to understand, given that hatchery strains of rainbow trout have hybridized and introgressed with cutthroat trout almost everywhere such introductions have occurred (Allendorf et al. 2005; Rubidge and Taylor 2005). Nevertheless, in the future, stocking should be limited to supplementation of populations considered incapable of recovering on their own and then only with closely related populations from either healthy local populations or fish from the same DU.

The post-glacial origin of Athabasca River rainbow trout does not reduce the importance of conserving these trout. Athabasca River populations are one of only three sets of populations that occupy Arctic-draining rivers on the eastern slopes of the Rocky Mountains (Behnke 1992). Thus, the Athabasca River rainbow trout are found in the "Western Arctic" freshwater aquatic biogeographic region in Canada, and, therefore, qualify for separate assessment of conservation status in Canada. The genetic analysis showing that Athabasca rainbow trout are not as genetically distinct as authors such as Carl et al. (1994) have suggested, leaves open the possibility of supplementing or supplanting Athabascan populations with fish from the same DU in the event of a continued, region-wide population decline. In the absence of other data at this point, such populations could include other native populations of the Western Arctic biogeographic region (sensu COSEWIC 2004) or fish that are most genetically similar such as fish from the upper Fraser River area (Taylor et al. 2007). Before such measures can be undertaken, however, it would be prudent to also assess the levels of differentiation between Athabasca rainbow trout and other putative source populations in traits controlled by quantitative genetic variation. It is the variation in quantitative traits (such as morphology, behaviour, physiology, life history) that are

more likely to influence persistence within the Athabasca River environments (e.g., Taylor 1991).

Native rainbow trout are not immediately at risk of extirpation in Alberta; however, these relatively small-bodied, slow-growing fish appear to be particularly vulnerable to over-fishing, habitat disturbance including anthropogenic climate change, and interactions with introduced brook trout. If current trends continue, native rainbow trout may ultimately be abundant only in the upper reaches of undeveloped watersheds.

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Appendix 1: Definitions of status ranks and legal designations.

A. The General Status of Alberta Wild Species 2005 (after Alberta Sustainable Resource Development 2007)

2005 Rank	1996 Rank	Definitions
At Risk	Red	Any species known to be *At Risk* after formal detailed status assessment and designation as *Endangered* or *Threatened* in Alberta.
May Be At Risk	Blue	Any species that may be at risk of extinction or extirpation, and is therefore a candidate for detailed risk assessment.
Sensitive	Yellow	Any species that is not at risk of extinction or extirpation but may require special attention or protection to prevent it from becoming at risk.
Secure	Green	Any species that is not *At Risk, May Be At Risk* or *Sensitive*.
Undetermined	Status Undetermined	Any species for which insufficient information, knowledge or data is available to reliably evaluate its general status.
Not Assessed	n/a	Any species that has not been examined during this exercise.
Exotic/Alien	n/a	Any species that has been introduced as a result of human activities.
Extirpated/Extinct	n/a	Any species no longer thought to be present in Alberta (Extirpated) or no longer believed to be present anywhere in the world (Extinct).
Accidental/Vagrant	n/a	Any species occurring infrequently and unpredictably in Alberta, i.e., outside its usual range.

B. Alberta Species at Risk Formal Status Designations
Species designated as *Endangered* under Alberta's *Wildlife Act* include those listed as *Endangered* or *Threatened* in the Wildlife Regulation (in bold).

Endangered	**A species facing imminent extirpation or extinction.**
Threatened	**A species likely to become endangered if limiting factors are not reversed.**
Species of Special Concern	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Data Deficient	A species for which there is insufficient scientific information to support status designation.

C. Committee on the Status of Endangered Wildlife in Canada (after COSEWIC 2006)

Extinct	A species that no longer exists.
Extirpated	A species that no longer exists in the wild in Canada, but occurs elsewhere.
Endangered	A species facing imminent extirpation or extinction.
Threatened	A species that is likely to become endangered if limiting factors are not reversed.
Special Concern	A species that may become threatened or endangered because of a combination of biological characteristics and identified threats.
Not at Risk	A species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient	A category that applies when the available information is insufficient to (a) resolve a wildlife species' eligibility for assessment, or (b) permit an assessment of the wildlife species' risk of extinction.

D. Heritage Status Ranks: Global (G), National (N), Sub-national (S) (after Alberta Natural Heritage Information Centre 2007a, NatureServe 2007)

G1/N1/S1	5 or fewer occurrences or only a few remaining individuals. May be especially vulnerable to extirpation because of some factor of its biology.
G2/N2/S2	6 to 20 or fewer occurrences or with many individuals in fewer locations. May be especially vulnerable to extirpation because of some factor of its biology.
G3/N3/S3	21 to 100 occurrences; may be rare and local throughout its range, or in a restricted range (may be abundant in some locations). May be susceptible to extirpation because of large-scale disturbances.
G4/N4/S4	Typically > 100 occurrences. Apparently secure.
G5/N5/S5	Typically > 100 occurrences. Demonstrably secure.
GX/NX/SX	Believed to be extinct or extirpated; historical records only.
GH/NH/SH	Historically known; may be relocated in the future.
G?/N?/S?	Not yet ranked, or rank tentatively assigned.

E. United States Endangered Species Act (after National Research Council 1995)

Endangered	Any species that is in danger of extinction throughout all or a significant portion of its range.
Threatened	Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Appendix 2. Rainbow trout abundance (# fish/0.1 ha) from single-pass electrofishing surveys in streams of the Upper Athabasca river system and an assessment of their risk status based on abundance. Low Risk (L), >50/0.1ha; Moderate Risk (M), 25-50/0.1ha; High Risk (H), <20/0.1ha. Land use categories include: L=logging activities, M=mining and F=recreational fishing.

Water body	Latitude	Longitude	Mean # fish/0.1ha	SE	n	Years	Risk category	Land Use
Athabasca River drainage:								
Baseline Creek	53.537	117.372	11.8	2.5	13	1996-98	H	L, F
Canyon Creek	53.511	117.431	11.1	2.1	9	1996-98	H	L, F
Centre Creek	53.450	117.534	24.6	12.8	2	1997	M	L, F
Chickadee Creek	54.330	116.183	14.7	4.3	9	1999-03	H	L, F
Felix Creek	53.725	117.382	38.6	----	1	1998	M	L, F
Fish Creek	53.488	117.653	21.4	3.9	23	1996-00	M	L, F
Gorge Creek	53.611	117.267	70.9	17.1	9	1996-98	L	L, F
Hardisty Creek	53.414	117.551	4.7	----	1	1999	H	L, F
Hunt Creek	53.459	117.409	3.2	----	1	1995	H	L, F
Marsh Creek	53.739	117.417	45.0	21.0	3	1996-98	M	L, F
Maskuta Creek	53.274	117.740	4.8	----	1	1996	H	L, F
Nosehill Creek	53.842	116.904	1.3	----	1	1997	H	L, F
Obed Creek	53.615	117.136	16.6	----	1	1997	H	L, F
Oldman Creek	54.134	116.111	16.1	4.8	7	1996-99	H	L, F
Oldman Creek			77.0	31.5	6	2000-03	L	L, F
Plante Creek	53.680	117.274	12.4	6.8	4	1996-98	H	L, F
Ponoka Creek	53.484	117.287	22.4	----	1	1995	M	L, F
Seabolt Creek	53.292	117.681	6.6	4.5	4	1995-99	H	L, F
Solomon Creek	53.409	117.959	2.6	0.7	11	1996-01	H	L, F
Two Creek	54.364	116.374	2.4	1.3	3	1999	H	L, F
Unnamed	53.996	116.414	55.8	24.3	7	1999-02	L	L, F
Unnamed	54.094	116.374	203.3	64.1	5	1999-02	L	L, F
Unnamed	54.275	116.257	197.4	154.0	6	1999-02	L	L, F
Unnamed	53.996	116.414	41.7	8.1	7	1999-03	M	L, F
Unnamed	54.328	116.107	44.8	17.7	5	2000-02	M	L, F
Unnamed/Emerson Creek	53.704	117.157	20.4	4.3	8	1998-01	H	L, F
Unnamed/Lynx Creek	53.843	116.998	67.1	14.0	12	1996-01	L	L, F
Unnamed/Roundcroft Creek	53.517	117.346	208.9	237.1	2	1993-98	L	L, F

Appendix 2 continued:

Water body	Latitude	Longitude	Mean # fish/0.1ha	SE	n	Years	Risk category	Land Use
Wildhay/Berlund River Drainage:								
Berland River	53.751	118.357	11.8	1.0	2	1998	H	L, F
Little Berland River	53.694	118.229	4.7	3.5	6	1993-98	H	L, F
Big Creek	53.849	118.126	11.1	4.4	4	1993-98	H	L, F
Cabin Creek	53.769					1997	H	L, F
Fox Creek	53.716	118.248	12.3	8.9	2	1993-96	H	L, F
Hendrickson Creek	53.805	118.465	12.1	5.4	2	1993-97	H	L, F
Moon Creek	53.763	118.355	6.7	1.9	7	1993-97	H	L, F
Moon Creek			5.1	1.4	11	1998-01	H	L, F
Unnamed/Beaver Creek	53.996	117.393	1.5	0.8	3	1993-98	H	L, F
Unnamed/Grizzly Creek	53.949	117.802	2.6	0.4	3	1993-95	H	L, F
Vogel Creek	53.772	118.426	8.7	2.7	2	1993-97	H	L, F
Cabin Creek	53.769	118.385	9.3	2.2	2	1993-97	H	L, F
Wildhay River	53.477	118.276	1.7	0.8	8	1993-99	H	L, F
Barbara Creek	53.599	117.691	5.5	3.6	2	1996-97	H	L, F
Carson Creek	54.390	115.738	2.2	----	1	1999	H	L, F
Collie Creek	53.509	118.123	39.2	12.4	2	1993-96	M	L, F
Fred Creek	53.605	118.079	143.0	140.5	2	1997-01	L	L, F
Hightower Creek	53.750	117.963	2.2	1.5	2	1993-96	H	L, F
Maria Creek	53.695	117.841	37.5	----	1	1998	M	L, F
Moberly Creek	53.556	118.009	17.8	7.4	3	1993-98	H	L, F
Pinto Creek	53.640	118.110	2.0	0.4	7	1993-01	H	L, F
Teitge Creek	53.618	118.123	3.9	----	1	1996	H	L, F
Twelve Mile Creek	53.502	117.898	32.0	7.0	6	1993-99	M	L, F
Unnamed	53.808	117.994	14.7	6.8	3	1982-96	H	L, F
Unnamed	53.229	116.845	3.2	0.3	2	1996-97	H	L, F
Unnamed	54.584	115.566	26.5	11.5	3	1997-03	M	L, F
Unnamed	53.492	118.113	1.4	----	1	1998	H	L, F
Wildcat Creek	53.732	117.984	32.2	29.4	2	1996	M	L, F
Wroe Creek	53.713	117.944	32.7	17.0	6	1982-01	M	L, F

Appendix 2 continued:

Water body	Latitude	Longitude	Mean # fish/0.1ha	SE	n	Years	Risk category	Land Use
McLeod River drainage:								
McLeod River	53.461	116.621	1.1	0.2	48	1998-01	H	L, F
Anderson Creek	53.320	117.400	72.5	20.5	8	1993-98	L	L, F
Anderson Creek			14.2	3.0	14	1999	H	L, F
Anderson Creek			15.2	4.3	3	2000	H	L, F
Anderson Creek			14.8	8.8	4	2001	H	L, F
Anderson Creek			5.6	0.5	4	2003-04	H	L, F
Antler Creek	53.201	117.331	25.4	5.9	8	1996-98	M	L,F
Antler Creek			36.4	23.5	9	1999-03	M	L,F
Beaverdam Creek	53.074	117.053	34.5	23.0	8	1993-00	M	L, F
Chief Creek	53.091	117.022	18.3	----	1	1995	H	L,F
Corral Creek	53.474	117.159	24.8	----	1	1983	M	L,F
Deerlick Creek	53.157	117.245	238.5	76.4	6	1996-97	L	L
Deerlick Creek			156.2	40.2	12	1998-99	L	L
Deerlick Creek			158.3	29.7	12	2000-04	L	L
Erickson 's Creek	53.083	117.004	20.8	----	1	1982	M	L,F
Eunice Creek	53.154	117.231	7.0	1.8	10	1993-99	H	L
Eunice Creek			6.5	3.0	6	2000-03	H	L
Little MacKenzie Creek	53.032	117.169	19.5	8.6	5	1998-01	H	F
Luscar Creek	53.061	117.302	6.6		1	1996	H	M
MacKenzie Creek	53.058	117.183	11.0	5.2	9	1983-01	H	F
Mary Gregg Creek	53.172	117.299	46.0	8.7	10	1993-03	M	M,F
McCardell Creek	53.221	117.298	4.8	1.1	2	1982-98	H	L,F
McPherson Creek	53.385	117.349	19.5	7.5	4	1993-98	H	L,F
Meadow Creek	52.985	117.154	1.7	----	1	1998	H	L, F
Mercoal Creek	53.160	117.084	44.6	24.5	3	1983-98	M	L,F
Moose Creek	53.544	116.378	5.4	3.5	2	1998	H	L,F
Quigley Creek	53.341	117.385	11.4	6.0	4	1982-03	H	L,F
Rainbow Creek	53.012	117.100	8.5	5.2	4	1995-99	H	L,F
Taylor Creek	53.069	117.025	22.5	15.8	5	1993-99	M	L,F
Thompson Creek	53.034	117.067	23.8	8.5	3	1997-00	M	L,F
Trapper Creek	53.143	117.344	130.3	47.6	4	1993-97	L	L,F
Unnamed	53.175	116.894	43.2	13.2	5	1995-03	M	L,F
Unnamed	53.735	117.552	32.0	28.0	3	1997-98	M	L,F
Unnamed	53.986	116.063	99.2	14.6	4	2001-02	L	L,F
Unnamed/Nice Creek	53.196	117.420	32.2	6.3	8	1982-02	M	L,F
Unnamed/Trout Creek	53.890	116.341	22.2	9.6	8	2000-02	M	L,F

Appendix 2 continued:

Water body	Latitude	Longitude	Mean # fish/0.1ha	SE	n	Years	Risk category	Land Use
Wampus Creek	53.160	117.262	310.6	67.0	8	1990-97	L	L
Wampus Creek			149.4	49.8	12	1998-99	L	L
Wampus Creek			262.3	86.2	18	2000-04	L	L
Watson Creek	53.053	117.281	56.4	19.5	5	1982-00	L	F
White Creek	53.299	117.127	20.1	8.9	5	1995-04	M	F
Embarras River	53.137	116.990	16.6	5.5	7	1997-99	H	L, F
Baril Creek	53.383	116.913	6.7	5.4	2	1998-01	H	L, F
Bryan Creek	53.231	116.978	52.1	42.1	3	1998-01	L	L, F
Chance Creek	53.187	117.036	46.1	----	1	1996	M	L, F
Dummy Creek	53.150	116.953	10.6	7.8	2	1996-97	H	L,F
Hay Creek	53.228	116.956	145.7	92.9	2	1982-04	L	L,F
Lambert Creek	53.365	116.961	8.8	2.4	10	1998-02	H	L,F
Lost Creek	53.165	117.019	11.4	3.2	3	1982-00	H	L,F
McNeill Creek	53.318	116.933	7.4	5.3	2	1982	H	L,F
Mitchell Creek	53.319	116.813	9.0	6.1	7	1995-04	H	L,F
Unnamed	53.248	116.855	24.1	0.5	2	1995	M	L,F
Unnamed	53.396	117.062	187.8	59.4	5	1996-01	L	L,F
Erith River	53.149	116.912	39.0	17.2	12	1995-04	M	L,F
Bacon Creek	53.144	116.785	49.2	10.0	3	1996-99	M	L,F
Halpenny Creek	53.150	116.758	163.1	100.1	5	1996-01	L	L,F
Hanlan Creek	53.183	116.506	18.9	17.8	2	1996-97	H	L,F
Lund Creek	53.093	116.611	88.1	47.2	2	1996	L	L,F
Raven Creek	53.299	116.575	2.4	0.7	2	1997-98	H	L,F
Rodney Creek	53.421	116.651	1.2	0.4	2	1996-00	H	L,F
Unnamed	53.486	118.042	125.6	49.7	3	1998-00	L	L,F
Unnamed/Tributary to Erith River	53.134	116.806	177.6	37.0	7	1996-01	L	L,F
Wickham Creek	53.209	116.725	80.6	44.0	2	1998	L	L,F
Unnamed	54.612	115.969	3.6	0.6	5	2002	H	L,F
Unnamed	54.601	115.788	9.1	6.1	3	2002	H	L,F
Gregg River	53.252	117.353	5.5	2.3	12	1996-04	H	M,L,F
Berry's Creek	53.097	117.447	1.8	10.3	3	1996-97	H	M,L,F
Teepee Creek	53.248	117.521	48.4	35.7	6	1996-00	M	M,L,F
Warden Creek	53.200	117.536	30.6	19.2	2	1996-98	M	M,L,F
Wigwam Creek	53.269	117.506	43.3	16.4	6	1982-01	M	M,L,F
Unnamed	53.076	117.428	11.5	----	1	1996	H	M,L,F

Appendix 2 continued:

Water body	Latitude	Longitude	Mean # fish/0.1ha	SE	n	Years	Risk category	Land Use
Freeman River drainage:								
Louise Creek	54.575	115.662	1.8	----	1	1996	H	L, F
Unnamed	54.586	115.744	2.2	0.5	2	1996-02	H	L,F
Unnamed	54.528	115.629	0.7	----	1	1996	H	L, F
Unnamed	54.564	115.621	9.1	6.2	3	2002	H	L, F

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